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Specification

[Name of the Invention] Manufacturing Method for Al-Mg-Si Aluminum Alloy Sheets with Excellent Bake Hardenability

[Technical Field]

[0001]

The present invention relates to a manufacturing method for Al-Mg-Si alloy sheets. The present invention concerns a manufacturing method for Al-Mg-Si aluminum alloy sheets, characterized in that a molten aluminum alloy metal containing a predetermined amount of Mg, Si as essential elements besides Al, and additionally in some cases a predetermined amount of Fe, Cu, Mn, and Cr is used, and during continuous casting of this, casting so that the average cooling rate at the time of solidification is 20 degrees C or above, and making the temperature of the ingot at the time it is taken out of the casting machine 250 degrees C or below, or cooling the ingot so that the temperature of the ingot is 250 degrees C or below within two minutes after the molten metal is poured into the casting machine, and further, after then having done rolling to the final sheet thickness by cold rolling only and without homogenization or hot rolling, solution treatment is done in a continuous annealing furnace. The Al-Mg-Si alloy sheet obtained by the present invention has excellent bake hardenability, so that by making use of this property, it may be utilized widely for vehicles such as cars, outer panels for household electrical appliances and the like, building materials and the like.

[Background Art]

[0002]

For example, cold-rolled steel has been used conventionally for automobile panel materials. However, recently, as a measure for reducing the weight of automobile bodies with the aim of improving fuel efficiency and reducing exhaust gases, a trend towards using aluminum alloy materials that are lightweight and have high specific strength, and have excellent metal forming processability is rapidly increasing. Among these, as an aluminum alloy sheet for automobiles that is often used with a paint coating for aesthetic improvement, Al-Mg-Si alloy, with its excellent bake hardenability, is getting attention, and its practical realization is being advanced in some quarters.

[0003]

However, the method that has generally been implemented in the past as a manufacturing for aluminum alloy sheets is the method whereby after scalping and homogenization, the

processes such as hot rolling, cold rolling, and annealing are sequentially performed on an ingot produced by a semi-continuous casting method. Conventional aluminum alloy sheets produced through such processes, since their press formability is excellent, and their bake hardenability is also excellent, were sufficient for the requirements of customers.

[0004]
However, the requirements of customers in recent years have become more stringent, and not only is there a tendency to seek higher strength in order to achieve weight reduction, but also further improvements in formability and bake hardenability are=required, and further, the requirements of cost reduction by improving productivity are further increasing.

[0005]
As relatively new aluminum alloy sheet manufacturing technologies that meet these requirements, methods whereby after an ingot is made by continuous casting, this is immediately sent to the rolling process such as hot rolling and cold rolling are performed (herebelow called the continuous/direct rolling method) and scalping and homogenization are omitted are being considered (JP-A S55-27497, examined patent application publication S62-54182 and the like). According to these methods, in addition to promoting cost reduction by the omission of scalping and homogenization, since the solute elements in a super-saturated solid solution are not precipitated during homogenization, there is the advantage that the strength of aluminum alloy sheets is improved due to solid solution strengthening.
[Patent Citation 1] JP-A S55-27497
[Patent Citation 2] Examined Patent Application Publication S62-54182

[0006]
A method has been proposed whereby, during the production of an aluminum alloy sheet using molten aluminum alloy, hot rolling is done after continuous casting, and cold-rolling is further done, the precipitation of super-saturated solute elements during the sequence of the processes of continuous casting, hot rolling, cold rolling, and intermediate annealing in particular is reduced as much as possible, and the strength of the final cold rolling product is increased, and bake hardenability and press formability are improved markedly (JP-A H7-252616). This method uses a molten aluminum alloy containing specific amounts of alloy elements such as Mg, Mn, and Si in particular, and manufactures an Al-Mg-Si alloy sheet by hot rolling after continuous casting, and further performing cold rolling, but at that time, by regulating the cooling rate during continuous casting and after hot rolling, and additionally by controlling the heat processing conditions after the cold rolling that is

subsequently performed, an Al-Mg-Si alloy sheet with improved press formability and bake hardenability and the like is obtained.

[Patent Citation 3] JP-A H7-252616

[0007]

Continuous casting methods utilized in such continuous casting/direct rolling methods that are currently practically realized are the water cooled continuous casting method (a continuous casting method whereby continuous casting slabs that are formed into sheets and come out of a stationary type water cooled continuous casting mold are directly cooled and solidified), a twin roll casting method developed at Hunter Engineering (a continuous casting method whereby molten metal is supplied between a pair of rotating cooled rollers, and cooling and solidification is done between said rollers), a belt type continuous casting method developed at Hazelett (a method whereby molten metal is supplied between two movable belt-shaped cooling members, and casting in the shape of a sheet continuously while cooling and solidifying between said belts), a block-type continuous casting method developed at Swiss Aluminum (a method whereby molten metal is supplied between two movable block-shaped cooling members, and casting in the shape of a sheet while cooling and solidifying between said blocks), and the like.

[Disclosure of the Invention]

[Problem to be Overcome by the Invention]

[0008]

However, in the continuous casting/direct rolling methods that are presently practically realized, intermediate annealing is done at a relatively low temperature in the range of 350 to 500 degrees C in order to prevent process cracking, but a problem arises in that precipitation of super-saturated solute elements occurs during the intermediate annealing process, and inhibits strengthening of the final cold rolling product. Additionally, in the methods described above, that is, methods wherein molten aluminum alloy are used for which the contained amount of alloy elements such as Mg, Mn, and Si in particular are specified, and during manufacturing of an Al-Mg-Si alloy sheet by hot rolling after continuous casting, and further cold rolling, by regulating the cooling rate during continuous casting and after hot rolling, and additionally by controlling the heat processing conditions after the cold rolling that is subsequently performed, an Al-Mg-Si alloy sheet with improved press formability and bake hardenability and the like is obtained, there is a problem in that hot rolling after the continuous casting, and heat processing after the cold rolling is needed, making the cost high so that the advantages of continuous casting cannot be utilized. Furthermore, in the obtained aluminum alloy sheet, the press formability and the bake hardenability leave room for further improvement.

[Means for Solving the Problems]

[0009]

The present invention was made with attention to the problems with the conventional art described above, and concerns a manufacturing method for Al-Mg-Si aluminum alloy sheets with excellent bake hardenability, characterized in that during twin belt casting of Al-Mg-Si aluminum, casting is done at an average cooling rate of 20 degrees C per second or above at the time of solidification, and the temperature of the ingot when coming out of the casting machine is 250 degrees C or below, and additionally, the ingot is cooled so that the ingot temperature is 250 degrees C or below within 2 minutes from pouring the molten metal into the casting machine, and further, after subsequently rolling to the final sheet thickness by cold rolling and without homogenization or hot rolling, solution treatment is done in a continuous annealing furnace.

[0010]

The first invention for solving the abovementioned problems is a manufacturing method for Al-Mg-Si aluminum alloy sheets with excellent bake hardenability, the main points being that a molten Al-Mg-Si aluminum alloy comprising Mg: 0.3 – 1.0 wt%, Si: 0.3 – 1.5 wt%, Cu: 1.0 wt% or below (including 0%), Fe: 1.2 wt% or below (including 0%), and according to need, containing Mn: 0.1 – 0.7 wt% and/or Cr: 0.1 – 0.3 %, and the remnant being Al is twin belt cast at an average cooling rate of 20 degrees C per second or above at the time of solidification, and at this time, the temperature of the ingot coming out of the casting machine is 250 degrees C or below, and subsequently rolling is done to the final sheet thickness by cold rolling and without homogenization or hot rolling, and solution treatment is done in a continuous annealing furnace.

[0011]

The second invention for solving the abovementioned problems is a manufacturing method for Al-Mg-Si aluminum alloy sheets with excellent bake hardenability, the main points being that a molten Al-Mg-Si aluminum alloy comprising Mg: 0.3 – 1.0 wt%, Si: 0.3 – 1.5 wt%, Cu: 1.0 wt% or below (including 0%), Fe: 1.2 wt% or below (including 0%), and according to need, containing Mn: 0.1 – 0.7 wt% and/or Cr: 0.1 – 0.3 %, and the remnant being Al is twin belt cast at an average cooling rate of 20 degrees C per second or above at the time of solidification, and at this time, the ingot is cooled so that the ingot temperature is 250 degrees C or below within 2 minutes of pouring molten metal into the casting machine, and after this rolling is done to the final sheet thickness by cold rolling and without homogenization or hot rolling, and solution treatment is done in a continuous annealing furnace.

[0012]

The reason for making the average cooling rate 20 degrees C or above is that if the average cooling rate is less than 20 degrees C per second, coarse Mg_2Si readily precipitates during solidification, and this coarse Mg_2Si is difficult to be dissolved into the matrix sufficiently during solution treatment with a continuous annealing furnace, so as a result, the bake hardenability is inferior.

[0013]

The reason for making the temperature of the ingot when coming out of the casting machine 250 degrees C or below is that if said temperature is above 250 degrees C, since Mg_2Si precipitates during the cooling process of the ingot, the temperature and time needed for the solution treatment of the final sheet with a continuous annealing furnace increases, and as a result, bake hardenability is inferior.

[0014]

The reason for not doing homogenization or hot rolling is that even if the precipitation of Mg_2Si is suppressed during the casting and cooling processes, since Mg_2Si precipitates again during homogenization or hot rolling, it becomes difficult to be dissolved into the matrix sufficiently during solution treatment, and as a result, the bake hardenability is inferior.

[0015]

The reason for cooling the ingot to 250 degrees C or below within 2 minutes of pouring the molten metal is that if 2 minutes is passed, the precipitation of Mg_2Si occurs, and it becomes difficult to dissolve this Mg_2Si into the matrix during solution treatment of the final sheet with a continuous annealing furnace, and as a result, bake hardenability is inferior.

[0016]

In order to make the temperature of the ingot when it comes out of the casting machine 250 degrees C or below, it is necessary to take away approximately 2200 MJ of heat or more from the ingot inside the casting machine for every 1 m^3 of the volume of the ingot. In the case of casting an ingot with a width of 1 m and a sheet thickness of 1 cm in a casting machine with an effective cooling length of 1 m, at a casting speed of 8 m per minute, this corresponds to casting with an average removed heat flow density of 3.0 MW/m^2 inside the casting machine.

[0017]
By making the temperature of the ingot after casting 250 degrees C or below, or by cooling the ingot so that it is 250 degrees C or below within 2 minutes from pouring the molten metal, and further, by rolling to the final sheet thickness using only cold rolling, without subsequent homogenization or hot rolling, it is possible to reduce the precipitation of coarse Mg_2Si, and during subsequent solution treatment with a continuous annealing furnace, Mg_2Si easily dissolves into the matrix. By doing so, in combination with having adjusted the composition of the Al-Mg-Si alloy appropriately, strengthening of the cold-rolling product is achieved, and proof stress after the subsequent baking treatment is increased, and further, an Al-Mg-Si alloy sheet is realized that is also markedly superior in press formability.

[0018]
Herebelow, the manufacturing conditions prescribed for the present invention including composition of the Al-Mg-Si alloy and cooling conditions during continuous casting and after heat rolling shall be explained in detail. First, the reason for prescribing the composition of the Al-Mg-Si alloy used in the present invention shall be explained.

[0019]
Mg (0.3 –1.0 wt%) is an element that forms Mg_2Si and contributes to strengthening, and it is necessary to include 0.3 wt% or above in order to secure the strength necessary for outer panel materials as described above. However, if the content is too high, this reduces formability, so that it is also necessary to keep the content at 1.0 wt% or below. A more preferable lower bound for Mg is 0.4 wt%, and a more preferable upper bound is 0.8 wt%.

[0020]
Si (0.3 – 1.5 wt%) is an element that forms Mg_2Si with the abovementioned Mg, and contributes to strengthening, and in order to effectively realize the effects of its addition, it is necessary to include 0.3% or above. However, if the content is too high, there is an adverse effect on press formability, so that it is also necessary to keep the content at 1.5 wt% or below. A more preferable lower bound for Si is 0.6%, and a more preferable upper bound is 1.2 wt%. As described above, in the present invention, Mg and Si form aggregates (clusters) of Mg_2Si composition called a G. P. zone, or an intermediate layer within the aluminum alloy, and are important elements that contribute to hardening by baking treatment.

[0021]
Cu (1.0 wt% or below) is not absolutely necessary, but it has a precipitation strengthening

effect, so that it is desirable to include proactively in cases where the demands for strength are high. However, if the content is too high, adverse effects will appear, so that it should be kept at 1.0 wt% or below. Considering the balance between strength and formability, a more preferable Cu content is in the range of 0.4 – 0.9 wt%.

[0022]

Fe (1.2 wt% or below) is also not absolutely necessary, but it has the effect of increasing strength, so that it is desirable to include proactively in cases where the demands for strength are high. However, if the content is too high, adverse effects will appear, so that it should be kept at 1.2 wt% or below. Considering the balance between strength and formability, a more preferable Fe content is in the range of 0.1 – 0.5 wt%.

[0023]

Mn (0.1 – 0.7 wt%) is an element that is effective as a solid solution strengthening element and a recrystallized grain refinement element, and in order to effectively realize these effects, 0.1 wt% or above must be included. However, if the content is too high, due to the increase in the amount of Mn that cannot be dissolved into a solid solution, a tendency to worsen the formability appears, so that it must be kept at 0.7 wt% or below.

[0024]

Cr (0.1 – 0.3 wt%) has an effect as a recrystallized grain refinement element, and in order to effectively realize these effects, a greater amount than the lower bound must be included. However, if the content surpasses the abovementioned upper bound, intermetallic compounds are generated and adverse effects appear. Considering these points, a desirable content for Cr is in the range of 0.1 – 0.3 wt%.

[0025]

The components making up the remnant of the aluminum alloy in the present invention are Al and unavoidable impurities, and examples of unavoidable impurities are Ni, Zn, Zr, V, Ti, Li and the like, but as long as these are in unavoidable impurity amounts, they will not be a particular obstacle for securing the properties intended for the present invention. Next, the conditions for continuous casting using the abovementioned Al-Mg-Si alloy, and cold rolling, shall be explained.

[0026]

If the average cooling rate at the time of solidification during continuous casting is prescribed in the above manner, the amount of Al-Fe-Si intermetallic compounds in the continuous cast structure decrease due to forced solid dissolution, and additionally, the size

of said Al-Fe-Si intermetallic compounds are refined to an average size of approximately 2 μm or below, and the press formability and bake hardenability are markedly increased. However, when the average cooling rate at the time of solidification during continuous casting is below the abovementioned rate, the amount of intermetallic compounds precipitated increases, and additionally their size becomes coarse, and not only does satisfactory press formability become unobtainable, but bake hardenability also becomes inferior.

[0027]
Additionally, after the abovementioned continuous casting, by making the temperature of the ingot 250 degrees C or below when it subsequently comes out of the casting machine, or by cooling the ingot so that the ingot temperature becomes 250 degrees C or below within 2 minutes after molten metal is poured into the casting machine, and further, by subsequently utilizing rapid cooling whereby rolling is done to the final thickness by cold rolling without homogenization or hot rolling, the precipitation of super-saturated solute components during ingot cooling is suppressed and the amount of super-saturated solid solution is maintained, and sheets that have excellent bake hardenability may be manufactured. Incidentally, if the temperature of the ingot after casting surpasses 250 degrees C, precipitation of super-saturated solute components occurs, and sheets with inferior bake hardenability are manufactured.

[0028]
After achieving the final sheet thickness by cold-rolling, solution treatment is performed in a temperature range of 530 – 570 degrees C in a continuous annealing furnace, and after quenching with hot or cold water, preliminary aging treatment is done. The reason for prescribing the solution treatment temperature at this time in the above manner is to suppress the precipitation of solute elements during solution treatment and maintain a sufficient super-saturated solute amount, and increasing strength, to increase bake hardenability by increasing the amount of solute elements. Incidentally, if the temperature of the solution treatment is below 530 degrees C, the improvement effect on bake hardenability also becomes insufficient. On the other hand, if the temperature surpasses 570 degrees C, the recrystallized grains become coarser, and additionally, burning due to eutectic melting occurs, and press formability is worsened.

[0029]
Additionally, after the abovementioned solution treatment, and after quenching with hot or cold water, by continuing on to perform preliminary heat treatment, an Al-Mg-Si alloy sheet with extremely excellent press formability and bake hardenability is obtainable. The

conditions for quenching and aging heat treatment are not particularly restricted, but as preferable conditions, the condition for quenching is hot water quenching, and the condition for aging heat treatment are approximately 10 minutes to 8 hours at 60 – 200 degrees C.

[0030]

The present invention, in addition to specifying the composition of an Al-Mg-Si alloy as described above, has the characteristic that during continuous casting using said molten alloy, casting is done so that the average cooling rate at the time of solidification is 20 degrees C or above, and the temperature of the ingot at the time it is taken out of the casting machine is made to be 250 degrees C or below, or the ingot is cooled so that the temperature of the ingot is 250 degrees C or below within two minutes after the molten metal is poured into the casting machine, and subsequently rolling to the final sheet thickness by cold rolling only and without homogenization or hot rolling, and prescribing the conditions for solution treatment in a continuous annealing furnace, and there are no specific restrictions on other conditions, but if other preferable conditions and the like are to be explained, then they are as follows.

[0031]

The present invention is characterized by continuous casting so that the ingot temperature is 250 degrees C or below, or cooling a continuously cast slab to 250 degrees C or below, rolling this up once, then rolling to the final sheet thickness by only cold rolling and without homogenization or hot rolling, and prescribing the conditions for solution treatment with a continuous annealing furnace, and due to this, compared to the method whereby after rolling up once after continuous casting, cooling is done and then homogenization or hot rolling is further done, the heat loss is small, and it is also effective for increasing productivity.

[0032]

Further, in carrying out the present invention, an aluminum alloy manufactured sheet is manufactured, by continuously manufacturing sheet-shaped slabs of a thickness of approximately 4 – 15 mm normally by continuous casting, by cold rolling this to a thickness of 0.1 – 1 mm after having rolled this up, and further performing solution treatment with a continuous annealing furnace and preliminary aging. Incidentally, as the continuous casting method utilized here, the aforementioned water-cooled type continuous casting method, twin roll type continuous casting method, belt type continuous casting method, block type continuous casting method, and the like may be selected as appropriate and utilized.

[Best Mode for Carrying Out the Invention]

[0033]

Next, embodiments of the present example shall be shown, but the present invention is not restricted to the embodiments described below, and it is of course possible to carry out by adding changes as seen fit that fit within the range of the points of the present invention, and these shall also be included within the technical scope of the present invention.

[Embodiment 1]

[0034]

Embodiment 1

An ingot of thickness 1 cm was cast on a twin belt casting machine under the following conditions:

Effective cooling length of casting machine: 1 m

Casting rate: 8 m/min

Molten metal pouring temperature: 700 degrees C

Composition: Al, Mg:0.6wt%, Si:0.8wt%, Fe:0.2wt%, Mn:0.2wt%, Ti:0.01wt%

[0035]

By changing the average removed heat flow density inside the casting machine, ingots with differing ingot temperatures immediately after casting were obtained.

Subsequently, after cold-rolling to a 1 mm sheet, and performing a solution treatment of 545 degrees C x 15 seconds → hot water quenching, preliminary aging of 85 degrees C x 8 hours was done, and T4 material was made. Additionally, for T6 material, after naturally aging T4 material for 1 week, 170 degrees C x 30 minutes of artificial aging was done. In order to evaluate bake hardenability, the proof stress of the T4 and T6 materials were measured, and the difference in the proof stress between T4 and T6 materials was taken to be the bake hardenability. Additionally, the target for superior bake hardenability was 100 MPa or above. Further, in order to see the effects of performing or not performing homogenization or hot rolling, the bake hardenability of sheets processed by homogenization or hot rolling was measured as comparative examples.

[0036]

[Table 1]

Number	1	2	3	4
Average removed heat flow density inside the casting machine (MW/m2)	3.3	3.3	3.3	2.8
Ingot temperatures immediately after casting (°C)	197	197	197	330
Homogenization	NO	YES	NO	NO
Hot rolling	NO	NO	YES	NO
T4-YS (MPa)	110	105	106	109
T6-YS (MPa)	215	180	190	198
Bake hardenability	105	75	84	91
Assessment	O	×	×	×
	Present example	Comparative example	Comparative example	Comparative example

Homogenization: 560 degrees C x 6 hours maintained → furnace cooling
Hot rolling: After raising temperature to 560 degrees C, hot rolling is done to 4 mm with the rolling start temperature at 550 degrees C. After this, cold rolling was done to 1 mm.

[0037]
Embodiment 2
An ingot with thickness 1 cm was cast on a twin belt casting machine under the following conditions:

Effective cooling length of casting machine: 1 m
Casting rate: 8 m/min
Molten metal pouring temperature: 700 degrees C
Composition: Al, Mg:0.6wt%, Si:0.8wt%, Fe:0.2wt%, Mn:0.2wt%, Ti: 0.01wt%

[0038]
A cooling device was attached at the exit opening of the casting machine so that the ingot may be cooled immediately after casting. When the cooling device was running, the

temperature of the ingots, which were 357 degrees C immediately after casting, by passing through the cooling device, were reduced to 230 degrees C within 2 minutes after pouring molten metal into the casting machine. In contrast, when the cooling device was not running, the temperature of the ingots 2 minutes after molten metal was poured into the casting machine was still hot at 330 degrees. After this, after cold-rolling to a 1 mm sheet, and performing a solution treatment of 545 degrees C x 15 seconds → hot water quenching, preliminary aging of 85 degrees C x 8 hours was done, and T4 material was made. Additionally, for T6 material, after naturally aging T4 material for 1 week, 170 degrees C x 30 minutes of artificial aging was done. In order to evaluate bake hardenability, the proof stress of the T4 and T6 materials were measured, and the difference in the proof stress between T4 and T6 materials was taken to be the bake hardenability. The target for superior bake hardenability was 100 MPa or above.

[Table 2]

Number	1	2
Average removed heat flow density inside the casting machine (MW/m2)	2.7	2.7
Ingot temperatures immediately after casting (°C)	357	357
Cooling device	YES	NO
Ingot temperatures 2 minutes after pouring molten metal	230	330
T4-YS (MPa)	108	107
T6-YS (MPa)	211	181
Bake hardenability	103	74
Assessment	○	×
	Present example	Comparative example